Derivation of Apollo 14 high-Al basalts at discrete times: Rb-Sr isotopic constraints. Hejiu Hui[1], Clive R. Neal[1], Chi-Yu Shih[2] and Laurence E. Nyquist[3] [1]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, [2]Jacobs Technology, ESCG, Mail Code JE23, Houston, TX 77058, [3]ARES, NASA-Johnson Space Center, Mail Code KR, Houston, TX 77058.

Introduction: Pristine Apollo 14 (A-14) high-Al basalts represent the oldest volcanic deposits returned from the Moon [1,2] and are relatively enriched in Al_2O_3 (>11 wt%) compared to other mare basalts (7-11 wt%). Literature Rb-Sr isotopic data suggest there are at least three different eruption episodes for the A-14 high-Al basalts spanning the age range ~4.3 Ga to ~3.95 Ga [1,3]. Therefore, the high-Al basalts may record lunar mantle evolution between the formation of lunar crust (~4.4 Ga) and the main basin-filling mare volcanism (<3.85 Ga) [4]. The high-Al basalts were originally classified into five compositional groups [5,6], and then regrouped into three with a possible fourth comprising 14072 based on the whole-rock incompatible trace element (ITE) ratios and Rb-Sr radiometric ages [7]. However, Rb-Sr ages of these basalts from different laboratories may not be consistent with each other because of the use of different ^{87}Rb decay constants [8] and different isochron derivation methods over the last four decades.

This study involved a literature search for Rb-Sr isotopic data previously reported for the high-Al basalts. With the re-calculated Rb-Sr radiometric ages, eruption episodes of A-14 high-Al basalts were determined, and their petrogenesis was investigated in light of the "new" Rb-Sr isotopic data and published trace element abundances of these basalts.

Rb-Sr Isotopic Provenance: The Rb-Sr isotopic data in the literature for pristine A-14 high-Al basalts [1,3, 10-21] were re-processed using the program *Isoplot 3.70* [9] with $\lambda(^{87}Rb) = 0.01402\ Ga^{-1}$ [8].

High-Al Basalt Eruption Episodes. A plot of all re-calculated radiometric ages and initial $^{87}Sr/^{86}Sr$ (I_{Sr}) of A-14 high-Al basalts is not discriminatory in distinguishing the isotopic provenance of each group due to large 2σ uncertainties associated with the calculated Rb-Sr ages and I_{Sr} (Fig. 1). Hence a weighted average age of each basalt group was calculated using the program *Isoplot 3.70* [9] (Fig. 1a). In the error-weighted average calculation, only errors from the isochron regression were propagated as 2σ internal errors [9]. A weighted average of I_{Sr} for each basalt group was also calculated using the same method (Fig. 1b). The weighted average age represents the crystallization age of each high-Al basalt group (i.e., the magma eruption time).

This re-evaluation of the Rb-Sr isotopic age data shows that Group B basalts erupted at 4.03±0.03 Ga and after Group A basalts (4.24±0.10 Ga) but before Group C basalts (3.92±0.03 Ga) (Fig. 1a). Clast 14321,371 has similar age and I_{Sr} to basalt 14072 (Fig. 1) though no whole-rock trace element data are available to verify its group assignment. Therefore, we tentatively group it with 14072 to form Group D high-Al basalts. The weighted average crystallization age of Group D basalts is 3.96±0.11 Ga, which is indistinguishable from the ages of those from Groups B and C (Fig. 1a), partially due to the relatively large error. However, Group D basalts can be separated from Group A, B and C basalts in terms of weighted average of I_{Sr} (Fig. 1b). This indicates that Group D basalts derived from a different source region compared to Group B and C basalts, which is consistent with their ITE data [7, 22]. A plot of weighted average age versus weighted average I_{Sr} does distinguish the isotopic provenance of Group A, B and C basalts (Fig. 2).

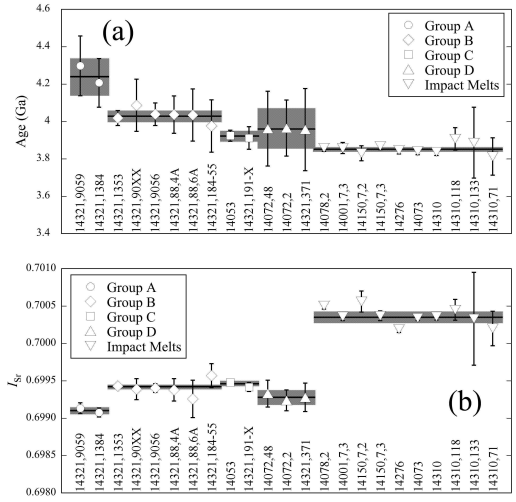

Fig 1. Weighted average Rb-Sr ages (a) and weighted average initial $^{87}Sr/^{86}Sr$ (b) of A-14 high-Al basalts and aluminous impact melts

Aluminous impact melts: Post-eruption activity. A-14 aluminous impact melts have higher I_{Sr} and are younger than the pristine high-Al basalts (Fig. 1). They also contain distinctly different ITE abundances (KREEP-like) compared to high-Al basalts [7,22]. The weighted average age and I_{Sr} of A-14 aluminous impact melts are 3.85±0.01 Ga and 0.700350±0.000075, respectively (Fig. 1) [9]. The scattering of initial $^{87}Sr/^{86}Sr$ data around the weighted average of I_{Sr} (Fig.

1b) partially may be due to differing $^{87}Sr/^{86}Sr$ in the target rocks.

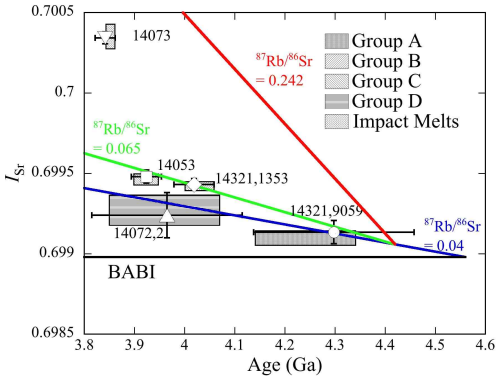

Fig. 2. Plot of weighted average of ages versus weighted average of initial $^{87}Sr/^{86}Sr$ of each group. The red and blue lines are evolution paths of the bulk moon ($^{87}Rb/^{86}Sr \approx 0.04$) and A14 KREEP ($^{87}Rb/^{86}Sr \approx 0.242$) respectively. One sample in each group is also plotted.

Geochemical Coherence within the High-Al Basalt Clan: Using Rb-Sr isotopic provenance (Fig. 2) and ITE ratios [7,22], A-14 high-Al basalts can be classified into three groups (A, B and C) and a tentative fourth group (D). Group A and D basalts fall on the evolution path of the bulk moon [23,24] (blue line in Fig. 2), while Group B and C basalts fall between the evolution paths of the bulk moon [23,24] and A-14 KREEP [25,26]. This, coupled with distinct ITE ratios, indicates that Group B and C basalts were derived from at least two distinct source regions. When all A-14 high-Al basalts, regardless of the fact that they formed at different times (Fig. 1), are taken into consideration, a general hyperbolic mixing curve [27,28] can fit available whole-rock Rb-Sr isotopic data with two end members of Group A basalt and A-14 KREEP (average of 14161,35,2; 14161,35,4; 14307,26,1 and 14163,65,2) [25,26] (Fig. 3a). This implies that the parental melts of high-Al basalts underwent similar evolutionary histories but at different times [23].

The melt products and sources of the different high-Al basalt groups were examined using whole-rock ITE data [7]. Whole-rock ITE ratios of pristine A-14 high-Al basalts can also be modeled via mixing [27,28] with the two end members being the Group A basalt composition and urKREEP [26] (Fig. 3b). By examining the parental melts for each of the groups (derived by [7]), it would appear that each source region (excluding Group D due to lack of data) contained variable proportions of KREEP (inset to Fig 3b). This is in addition to the assimilation that these basalts experienced during crystallization [7,22,23]. This strengthens the conclusions that the parental melts of A-14 high-Al basalts are geochemically correlated and that a KREEP component was also present in the Group B and C source regions, which is consistent with a previous study of olivine phenocrysts [29]. Both Rb-Sr isotopic compositions and ITE ratios show that parental melt compositions of A-14 high-Al basalts are genetically correlated through mixing of evolved components with a relatively primitive magma ocean cumulate.

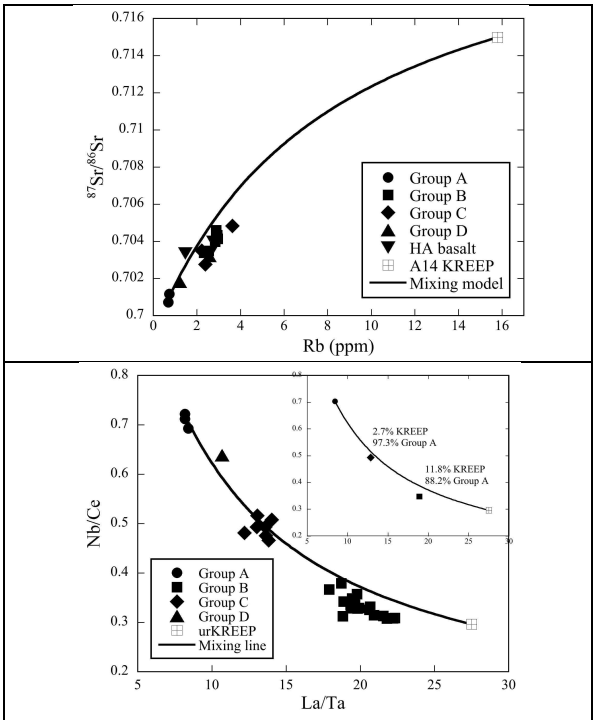

Fig. 3. Plots of (a) Rb versus $^{87}Sr/^{86}Sr$ and (b) La/Ta versus Nb/Ce.

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